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FABRICATION OF AL/FLY ASH MMC, IDENTIFYING MECHANICAL PROPERTIES & MULTI OBJECTIVE OPTIMIZATION FOR TURNING PROCESS USING GREY RELATIONAL ANALYSIS

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ABSTRACT

This paper investigates the effects and multi objective of optimization of turning process parameters. The process parameters selected for optimization are speed, feed and depth of cut. In this study Al-LM 25 has been selected as the base material which is having a wide variety of application in the cylinder block liners, vehicle drive shafts, bicycle frames automotive pistons etc. An attempt had been made to increase in strength by adding 12% of Fly-ash and 8% of Magnesium to make a metal matrix composite by Steer Casting process the hardness had been increased from 66.04 BHN to 78.14 BHN. The experimental runs are carried out based on L9 Orthogonal Array (OA). Surface Roughness (Ra) and Material Removal Rate (MRR) are taken as process responses. The objective of optimization is to achieve minimum surface roughness and high material removal rate simultaneously, process parameters are optimized based on Taguchi technique coupled with grey relational analysis. Analysis Of Variance (ANOVA) has been carried out to get the contribution of each process parameters on the process responses and final effects of process parameters on material removal rate and surface roughness is plotted and studied.

KEYWORDS: Al-LM25, Surface Roughness, Material Removal Rate, Grey Relational Analysis & MINITAB

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Nomenclature

OA - Orthogonal Array

R_a - Surface Roughness

MRR - Material Removal Rate

ANOVA - Analysis Of Variance

$X_i(Z)$ - Grey relational generation value

i - Grey relational grade

1. INTRODUCTION

In the earliest metal shaping techniques, casting is one of the process which is known to human being. It means pouring molten metal into a refractory mould cavity and allows it to solidify. The solidified object is taken out of the mould either by breaking or taking the mould part. The solidified object is called casting, and the technique followed by the method is known as casting process.

Turning is the ejection of metal from the outer estimation of a rotating barrel moulded work piece. Its key structure, can be described as the machining of an external surface.

Due to a low weight and low cost Al based LM25 particle reinforced metal matrix composite material is mostly used in the engineering materials. These finds many applications like cylinder block liners, vehicle drive shafts, bicycle frames automotive pistons etc.

1.1. Objective of Present Work

The main objective of the work is to develop a metal matrix composite of Al LM25-reinforced with fly-ash and to study the effect of particulate material effect with respect to hardness and turning parameters like depth of cut, cutting speed, feed rate of material removal rate and surface roughness. The above objective has been achieved by following steps.

- To prepare the Al LM25-reinforced Al composite by steer casting
- To characterize the composite material and find the hardness
- To identify ranges of process parameters for the turning of the above materials
- To perform the turning experiments and find out surface roughness, material removal rate.
- By using grey relational analysis, which is coupled with Taguchi method
- ANOVA is also performed to get the percentage contribution of each parameter on the process responses.

2. LITERATURE REVIEW

Previously, some researchers have been trying to optimize process parameters during machining. Kilickap et al.[1-2] developed a relationship between tool wear and surface roughness to cutting parameters for machining of homogenized sic-p reinforced aluminium metal matrix composite. The study emphasize on investigated the tool wear rate of different coated and uncoated tool and surface roughness in different cutting parameters. It was observed that increase in reinforcement element addition produced better mechanical properties such as impact toughness but tensile strength shoes different trends Er-Gallab and sklad [3] focused the effect of various cutting parameters on surface quality and extend of the sub-surface damage due to machining using PCD tools.

Puneet Bansal and Lokesh Upadhyay [4-5] Resulted that the uncoated tool is less compared to coated tool. Here the feed rate is very low to the cutting speed on weariness of the tool bit, but, the rate of giving feed is proportional to the tool wear. The machinability property of these composite materials is different when compared to the traditional materials, due to the abrasive reinforcement element and having of the abrasive nature of alumina effects more wear on cutting tool. It has been observed that the increase in reinforcement ratio effects surface roughness inversely. J. Palladium [6] found in

this study influence of machining conditions. Machining parameters, the contact time of the cutting tool while turning particulate metal matrix composites.

G. B. Veeresh kumar et al. [7] Investigated the influence of reinforcement on mechanical properties when different metal matrix materials that is Al6061 and Al 7075 and reinforcements such as SiC and Al_2O_3 are used and they observed micro hardness of the composite were increased with the increase of filler content. Venkata Prasad[8] has investigated on factors influencing the dry sliding wear behaviour such as load, sliding speed, reinforcement content in Al/Fly ash/Graphite hybrid metal matrix composite and the results reveals that load is the most significant parameters influencing the wear rate of the hybrid composite followed by the sliding speed and reinforcement content. G. Elango and B. K. Raghunath [9] resulted that, particulate reinforcement composite has high strength, hardness when compared with matrix materials the wear resistance increase in the hybrid composite materials when the sic and TiO_2 is added as reinforcement unreinforced aluminium alloy exhibits more were followed by sic reinforced binary metal matrix composites and then the hybrid composite composites (LM25+SiC+TiO_2).

Mr. Amol D. Sable, Dr. S. D. Deshmukh [11] Studied mechanical preparation of metal- matrix composite by stirring casting method. Satpal Kundu Dr. B. K. Roy, Ashok Kr Mishra [12] Resulted Study of Dry Sliding Wear Behavior of Aluminium/SiC/Al_2O_3/Graphite Hybrid Metal Matrix Composite Using Taguchi Technique. Siddesh Kumar N G Ravindranath V M G S Shiva Shankar [13] Investigated The hybrid composites prepared by stir casting technique for Al 2219 reinforced with hard B C & solid lubricant MoS C & solid lubricant MoS particles successfully.

Mr.Sharanabasappa R Patil, Prof B.S Motgi, Prof B.S Motgi [14] has explained that by stir casting method Al composite material can easily prepared and the metal matrix composite microstructure shows the uniformly distributed phases, and also explained that with the addition of Al2O3 the tensile strength and hardness of material increases. Whereas the ductile and impact strength decreases. P. Sathiaprathap, V. S. K. Vengatachalapathy, K. Palaniradja [15] concluded that selection of proper machining process for effective machining of hybrid Al/SiC/BC-MMC.

3. DETAILS OF THE EXPERIMENTS

3.1. Selection of the Workpiece Material

Al LM25 material having a wide variety of application in cylinder block liners, vehicle drive shafts, bicycle frames automotive pistons automobile industry. The industries are looking for less weight, high strength materials. Composites are the materials which can posses high strength with less weight. From the literature we selected Al LM25 as matrix material and fly-ash, magnesium as reinforcing materials

3.2. Manufacturing of Al/Fly Ash MMC

First fly-ash is heated to 6000c to remove the impurities and water content in the fly ash, and magnesium was 99.9% pure. Al LM25 was melted in the crucible at 8500c on muffle furnace and added fly-ash and magnesium and then they are mixed with steering machine and cast to shape of 35mm diameter and 196mm length.

Figure 3.1: Fly Ash

Figure 3.2: Stir Casting Arrangement

3.2.1. Stir Casting Method

In a stir casting process, the reinforcing phases are distributed into molten metal by mechanical stirring. The stir casting of MMC was initiated in 1968, when S. Ray introduced alumina particles into an aluminium melt by stirring molten aluminium alloys containing the ceramic powders. Atypical stir casting process of MMC is illustrated in fig Mechanical stirring in the furnace is a key element of this process by using scanning electron microscopy. The resultant molten alloy, with ceramic particles, can be used in sand casting. Stir casting is suitable for manufacturing composites

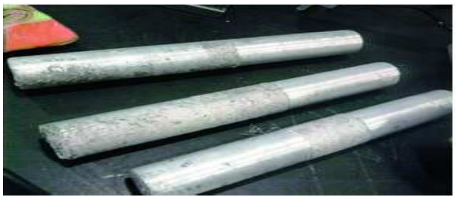

Figure 3.3: Crucible used for Casting

Figure 3.4: Workpiece of Composite

3.2. Characterization of Workpiece Material

Table 3.1: Pure Material of Al-Lm25

Name of Samples	Al LM25 (gm)	Diameter of Specimen (mm)	Total Length of Specimen (mm)
S1	500	30	110
S2	400	30	90

Table 3.2: The Composition used for Metal Matrix Composite

Name of Samples	Al LM25 (gm)	Magnesium (gm)	Fly Ash (gm)	Total Weight (gm)
S1	900	30	60	990

Table 3.3: Composition of MMC

Name of Samples	Al LM25 Wt %	Magnesium Wt%	Fly Ash Wt%
S2	100	8	12

3.3. Microstructures Study of Pure Material (Al-LM25) and Composite Material (Al-Lm25/Fly Ash/Mg)

The microstructures plays an important role for analysing the distribution of distinct phases in pure aluminium and aluminium matrix material. The microstructure was studied by using scanning electron microscope and which shows that the phases are near uniformly distributed in the metal matrix. And the images are shown below.

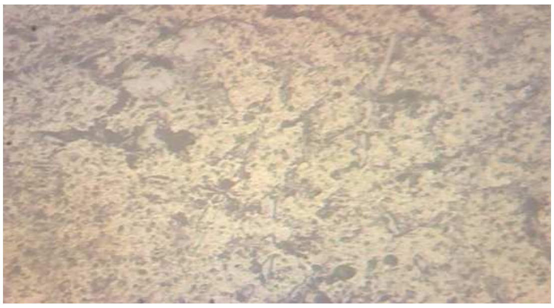

Figure 3.5: Microstructure of LM25

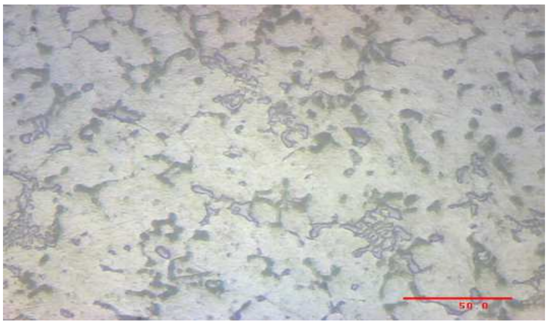

Figure 3.6: Microstructure of Lm25 with 8% Mg and 12% fly ash

4. HARDNESS TEST

4.1. Brinell Hardness Test

Hardness is defined as the resistance offered by the material to undergo mechanical deformation when load is applied. Three methods are used to measure hardness. Out of the three Brinell hardness testing is used to measure the resistance to the solidification behaviour when force is applied there is permanent shape change. The Macroscopic hardness is mainly characterized with strong intermolecular bonds. For getting the accuracy of the material there are three types of test, which are Vickers hardness test, the Rockwell hardness test and the Brinell hardness test. Out of these we concentrated with the Brinell hardness test.

The Brinell hardness testing was performed on the sample with a load of 250Kgf and the diameter of the steel ball indenter is 5mm. The impressions made by the steel ball were observed carefully and the diameters of the impressions were used to calculate the hardness value of the sample.

Brinell scale is a hardness scale based on the indentation hardness of a material. The Brinell test determines the hardness by measuring the depth of penetration of an indenter under a large load compared to the penetration made by a preload.

The measured hardness value of the base material Al-LM25 is 66.04. The hardness of the composite manufactured is measured and found it is increased by the value of 12.1, the measured hardness is 78.14. The increased hardness is because fly-ash, which is a ceramic and it’s had good hardness.

5. DESIGN OF EXPERIMENTS

5.1. Taguchi Method

To get different combinations of parameters and this level for each experiment, Taguchi proposed on the experimental plan in terms of orthogonal array. According to this technique, entire parameter space is studied with minimum number of experiments. This approach is based on the use of orthogonal arrays to conduct small, highly fractional factorial experiments up to larger full factorial experiment.

Table 5.1: Details of Process Parameters

Level	A Speed (rpm)	B Feed (mm/rev)	C Depth of Cut (mm)
1	1000	0.025	0.5
2	1500	0.05	0.75
3	2000	0.075	1

Table 5.2: Experimentation Design

Exp	A	B	C
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

In this research there are three process parameters, namely depth of cut, speed, feed rate. The orthogonal array chosen was L9, which has 9 rows corresponding to the number of parameter combinations.

Table 5.3: L9 Array of Process Parameter

Exp	Speed (rpm)	Feed (mm/rev)	DOC (mm)
1	1000	0.025	0.5
2	1000	0.05	0.075
3	1000	0.075	1
4	1500	0.025	0.075
5	1500	0.05	1
6	1500	0.075	0.5
7	2000	0.025	1
8	2000	0.05	0.5
9	2000	0.075	0.075

5.2. Selected Response Variable

The following response variables were selected for the present work

- Surface roughness (Ra),
- Material removal rate

5.3. Turning Experiment

The 30mm diameter and 110mm, 90mm length of two specimens (pure material) and 30mm diameter, 196mm length (MMC) work piece was subjected to turning on the lathe. After turning operation has been performed the surface roughness and material removal rate was measured with the help of the following experiments.

5.4. Surface Roughness

The surface roughness was measured by the Mitutoyo Company Talysurf equipment shown in figure 5.1.

Figure 5.1: Talysurf Equipment

5.5. Material Removal Rate

Chang in volume of Al-fly ash material after machining are calculated

MRR=[D-d] x f x N mm^3/min (1)

Where D= Before cutting diameter mm

d=After cutting diameter mm

f=cutting feed rate mm/rev

N=cutting speed rpm

6. RESULTS AND DISCUSSIONS

Table 6.1: Design of Experiment and Experiment Results for Pure Al (LM25) Material

Exp runs	Speed (rpm)	Feed (mm/rev)	DOC (mm)	Ra (μm)	MRR
1	1000	0.025	0.5	1.22	0.545
2	1000	0.05	0.75	1.52	1.6275
3	1000	0.075	1	1.50	3.24
4	1500	0.025	0.75	1.24	1.220
5	1500	0.05	1	1.29	3.24
6	1500	0.075	0.5	1.40	2.45
7	2000	0.025	1	1.22	2.16
8	2000	0.05	0.5	1.25	2.18
9	2000	0.075	0.75	1.18	4.8825

Table 6.2: Design of experiments and Experiment results for MMC

Exp Runs	Speed (rpm)	Feed (mm/rev)	DOC (mm)	Ra (μ)	MRR (m^3/min)
1	1000	0.025	0.5	2.22	0.545
2	1000	0.05	0.75	1.611	1.6275
3	1000	0.075	1	4.42	3.24
4	1500	0.025	0.75	1.506	1.220
5	1500	0.05	1	3.389	3.24
6	1500	0.075	0.5	3.03	2.45
7	2000	0.025	1	1.215	2.16
8	2000	0.05	0.5	1.169	2.180
9	2000	0.075	075	1.348	4.8825

Material removal rate and surface roughness of Al-fly ash after machining are shown in Table 6.1. Single responses can be optimized by Taguchi method, but machining has multiple responses, whereas Taguchi method may not be helpful while optimizing the process parameters, grey relation analysis coupled with Taguchi method is generally used for multiple responses.

6.1. Grey Analysis

The experimental results obtained from surface roughness and Material removal rate are presented in Table 5.3 and Table 6.1. Grey relational grade is the final response for optimizing process parameters with Taguchi analysis, which is attained from the following set of calculations.

6.1.1. Grey Relational Generation for Pure Material and MMC Material

Grey relational generation is the first step in grey Taguchi analysis in which experimental results should be normalized in the range of 0 to 1. For normalizing surface roughness data, lower-the-better (LB) criterion used (equation 2) and for normalizing material removal rate data, higher-the-better (HB) criterion are used (equation 3).

$$X_i(z) = \frac{\max y_i(z) - y_i(z)}{\max y_i(z) - \min y_i(z)} \quad (2)$$

$$X_i(z) = \frac{y_i(z) - \min y_i(z)}{\max y_i(z) - \min y_i(z)} \quad (3)$$

Where $X_i(z)$ is the grey relational generation value, max $Y_i(z)$ is the greatest value of $Y_i(z)$ for z^{th} response. Min $Y_i(z)$ is the smallest value associated with $Y_i(z)$ for z^{th} response. The normalized data for pure material after grey relational generation is given table 6.2. The normalized data for MMC material after grey relational generation is given table 6.3. Best value in normalized result is the best performance value it should be equal to 1.

Table 6.3: Normalized of Experiments Data for Pure Material

Exp Runs	Ra	MRR
1	0.882	0
2	0	0.250
3	0.058	0.621
4	0.823	0.156
5	0.676	0.621
6	0.353	0.440
7	0.882	0.372
8	0.794	0.377
9	1	1

Table 6.4: Normalized of Experiments Data for Composite Material

Exp runs	Ra	MRR
1	0.676	0
2	0.864	0.250
3	0	0.621
4	0.896	0.156
5	0.317	0.621
6	0.428	0.440
7	0.986	0.372
8	1	0.377
9	0.945	1

6.1.2. Grey Relational Coefficient for Pure and MMC Material

After normalizing surface roughness and MRR response data, grey relational coefficients are calculated to exhibit relationship between the best and actual normalized experimental results. The grey relational coefficient €$_i$(z) can be expressed as

$$\varepsilon i\ (z) = \frac{\Delta_{min} + \varphi\Delta_{max}}{\Delta_{oi}(z) + \varphi\Delta_{max}} \quad (4)$$

Where, $\Delta_{0i} = X_{0i}(z) - X_i(z)$, Δ_{0i} is the difference of absolute value between $X_0(z)$ and $X_i(z)$. Δ min is the minimum value of Δ_{0i} and Δ min is the maximum value of Δ_{0i}. φ is the identification coefficient, the value of φ in the range of 0< φ<1, the suggested value of the distinguishing coefficient, φ is 0.5, due to moderate distinguishing effects and good stability of outcomes. In this study, φ value is taken as 0.5 for further analysis. The grey relational coefficient values for surface roughness and MRR are shown in table 6.3 and 6.4.

Table 6.5: Grey Relational Coefficient for Pure Material

Exp No.	Ra	MRR
1	0.809	0.333
2	0.333	0.40
3	0.346	0.569
4	0.738	0.372
5	0.606	0.569
6	0.436	0.472
7	0.809	0.443
8	0.708	0.445
9	1	1

Table 6.6: Grey Relational Coefficient for MMC Material

Exp No.	Ra	MRR
1	0.6	0.333
2	0.786	0.40
3	0.333	0.569
4	0.828	0.372
5	0.423	0.569
6	0.466	0.472
7	0.973	0.443
8	1	0.445
9	0.91	1

6.1.3. Grey Relational Grade and Grey Relational Ordering for Pure and MMC Material

Grey relational grade is taken as an overall process response instead of multiple response such as surface roughness and MRR. Grey relational of grade is calculated by averaging the grey relational coefficient values of multi responses as follows and it is indicated by Yi.

$$\gamma\ \mathrm{i} = \frac{1}{n}\sum_{z=1}^{n} \varepsilon\ \mathrm{i}\ (\mathrm{z}) \qquad (5)$$

Where, n= number of responses

Higher value of grade indicates the best relational degree between the $X_o(z)$ and $X_i(z)$. Table 6.6 and 6.7 shows that the grey relational grade and their orders.

Table 6.7: Grey Relational Grade & Order for Pure Material

Exp No.	Grade	Order
1	0.571	5
2	0.733	9
3	0.915	7
4	0.555	6
5	0.587	3
6	0.454	8
7	0.626	2
8	0.576	4
9	1	1

Table 6.8: GRG & Order for MMC Material

Exp No.	Grade	Order
1	0.4665	8
2	0.593	5
3	0.451	9
4	0.6	4
5	0.496	6
6	0.469	7
7	0.708	3
8	0.7225	2
9	0.955	1

6.2. Factor Effects on Grey Relational Grade for Pure and MMC Material

The main effect plot for grey relational grade is shown in figure. In the main effect plot, a parameter for which the line has the highest inclination will have a more significant effect and the line which is near to horizontal line has no significant effect. From the main effect plot 6 it is clear that the depth of cut (C) has a more significant effect and feed has a less significant effect. The optimal parameter combination of pure Aluminium for minimum surface roughness and minimum MRR are A1 B3 C2 i.e. Speed of 1000 rpm, feed of 0.075 mm/rev and depth of cut of 0.75 mm. From the main effect plot 7 it is clear that Cutting Speed (A) has a more significant effect and feed has a less significant effect. The optimal parameter combination of MMC for minimum surface roughness and minimum MRR are A3 B1 C1 i.e. Speed of2000 rpm, feed of 0.025 mm/rev and depth of cut of 0.75 mm.

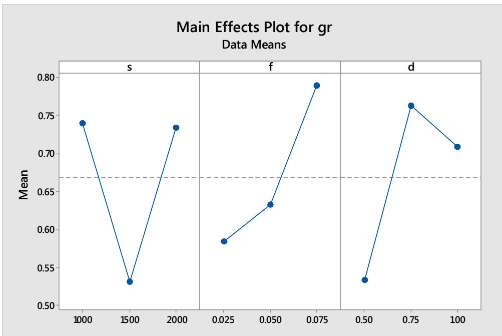

Figure 6.1: Main Effect Plot for Mean of GR for Pure

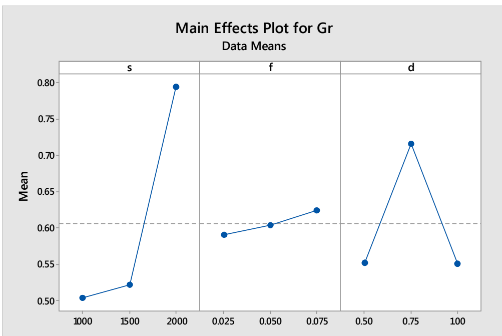

Figure 6.2: Main Effect Plot for GR for MMC

6.3. Analysis of Variance

The purpose of ANOVA is to investigate which process parameter has a significant effect on the process responses. In ANOVA values of p less than 0.050 indicates the parameter has significant effect and values more than 0.100 indicates the parameters are not significant. The percentage contribution can be calculated as:

$$P = \frac{SS_d}{SS_T} \tag{6}$$

Where ss_d is the sum of squared deviation for the each parameter and ss_t is the total sum of squared deviations. In this study, Analysis of variance (ANOVA) has been carried out by using MINITAB 17 software. Table 6.9 shows the Analysis of variance result in an overall grey relational grade of surface roughness and material removal rate for pure material. Table 6.10 shows the Analysis of variance result for overall grey relational grade of surface roughness and material removal rate for MMC material

Table 6.9: ANOVA for Grey Relational Grade for Pure Material

Source	DOF	Sum of Squares	Mean Squares	F-Ratio	% Contribution
S	2	0.0840	0.0420	4.07	32.33
F	2	0.0693	0.0346	3.36	26.68
D	2	0.0858	0.0429	4.15	33.02
Error	2	0.0206	0.0103		7.95
Total	**8**	**0.2660**			

Table 6.10: ANOVA for Grey Relational Grade for MMC Material

Source	DOF	Sum of Squares	Mean Squares	F-Ratio	% Contribution
S	2	0.16020	0.08010	33.92	72.709
F	2	0.00172	0.00086	0.36	0.781
D	2	0.05368	0.02684	11.37	24.363
Error	2	0.00472	0.00236		2.142
Total	**8**	**0.22033**			

7. CONCLUSIONS

The Al-LM25/Fly ash/Mg composite was successfully fabricated with the help of stir casting arrangement. With proper distribution of fly ash particles all over the specimen the composite was fabricated. By adding Mg to the composite it improves the usability of an ash particle by reducing its surface tension. The following conclusions have been drawn:

- Based on grey analysis, the optimal setting for obtaining minimum surface roughness and maximum material removal rate for pure material are A3 B2 D3 i.e. Speed of 2000 rpm, feed of 0.05 mm/rev and depth of cut of 1 mm.
- The hardness of the material has been increased by adding fly-ash, the hardness of Al-LM25 is 66.04 and hardness of Metal Matrix Composite is 78.14. The improved hardness is about 12.1.
- Based on grey analysis, the optimal setting for obtaining minimum surface roughness and maximum material removal rate for Al Lm25 – Fly ash are A3 B1 C2 i.e. Speed of 2000 rpm, feed of 0.025 mm/rev and depth of cut of 0.75 mm.
- ANOVA resulted that the cutting speed has been more influential parameter on Surface roughness and MRR for Al LM25 – Fly ash composite.

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